TNO Institute for Perception
TD912170
Kampweg 5
P.O. Box 23
3769 ZG Soesterberg
The Netherlands

Fax +31 3463 5 39 77
Telephone +31 3463 5 62 11

TNO Defence Research

TNO-report **IZF 1991 B-10**

C.A. McCann*
P.J.M.D. Essens

HUMAN COGNITIVE PROCESSES IN COMMAND AND CONTROL PLANNING. 2: SPLITS - AN ENVIRONMENT FOR EXPERIMENTS

*On scientific exchange from Defence and Civil Institute of Environmental Medicine, P.O. Box 2000, North York, Ontario, Canada M3M 3B9

Number of pages: 27

Netherlands organization for applied scientific research

TNO Defence Research consists of the TNO Physics and Electronics Laboratory, the TNO Prins Maurits Laboratory and the TNO Institute for Perception

CONTENTS

Report No.:	IZF 1991 B-10
Title:	Human cognitive processes in Command and Control planning. 2: SPLITS - An environment for experiments
Authors:	C.A. McCann and drs. P.J.M.D. Essens
Institute:	TNO Institute for Perception Group: Cognitive Psychology
Date:	August 1991
DO Assignment No.:	B91-35
No. in Program of Work:	733.2

SUMMARY

The report describes a laboratory-based task and environment for empirical investigation of human planning of activities in time and space. The environment, called SPLITS, presents planners with problems analogous to those encountered in command and control environments. The problem situation against which planning is carried out is a computer-based shopping game that can be played by one or two players. Aspects of the shopping environment, such as the layout of the store and its commodities and the number, mobility and sensing capabilities of the shopping robots, can be varied to give a range of planning task complexities. The report describes how SPLITS can be used to address research issues such as the structure of human planning processes and the information used in planning; the effects of uncertain information on planning; the circumstances under which replanning occurs and how it is carried out; and the effects of computer-based aids on the quality and efficiency of planning.

Rap.nr. IZF 1991 B-10

Instituut voor Zintuigfysiologie TNO
Soesterberg

Cognitieve processen in Command and Control planning. 2: SPLITS - Een omgeving voor experimenten

C.A. McCann en P.J.M.D. Essens

SAMENVATTING

In dit rapport wordt een beschrijving gegeven van een laboratoriumtaak en -omgeving voor empirisch onderzoek van menselijke planning van activiteiten in tijd en ruimte. In deze omgeving, SPLITS genaamd, krijgen planners problemen aangeboden die verwant zijn aan Command and Control planningsproblemen. In een computerspel, een winkelspel, moet een plan gemaakt worden waarin aangegeven wordt hoe robots in een winkel goederen moeten ophalen. Het spel kan door één of twee spelers of teams worden gespeeld. Bepaalde aspecten van de winkelomgeving (inrichting van de winkel en plaatsing van de goederen) en de winkelrobots (aantal, transport- en waarnemingsvermogen) kunnen worden gevarieerd, zodat probleemsituaties van verschillende complexiteit gecreëerd kunnen worden. Beschreven wordt hoe SPLITS gebruikt kan worden voor onderzoeksvragen m.b.t. de structuur van planningsprocessen en de informatie die gebruikt wordt in de planning, de effecten van onzekere informatie op planning, de omstandigheden waaronder herplanning optreedt en hoe herplanning verloopt, en de effecten van computerhulpmiddelen op de kwaliteit en efficiëntie van de planning.

1 INTRODUCTION

Planning is a component of almost every human interaction with the world. It is undertaken as a deliberate activity when a human or organization cannot immediately determine the response to a future situation, especially when that situation is one that has not been encountered before, is complex, or involves uncertainty. Planning involves the modelling and representation of the anticipated state of some world and the temporal organization of future actions to accomplish a goal or goals, given that state. Complex domains in which planning is an important function include those of business, manufacturing and military operations. In these domains, planning may also be supported by computer assistance.

Despite the pervasiveness of planning as an activity, the cognitive processes that contribute to its effective execution have not been addressed in much depth. In particular there is a paucity of controlled empirical studies focusing specifically on planning actions in complex dynamic environments. This lack of fundamental information on the process of human planning and its limitations also hampers the development of effective computer-based aids to assist planning.

Fundamental studies of human planning require first that typical dynamic planning situations facing a human planner be made tractable for experimental investigation; and second that there be a method for measuring the planning process. This paper describes a laboratory-based task and environment in which the important characteristics of dynamic planning situations are modelled. The paper explains how the environment and task can be manipulated to permit addressing of several important questions concerning human planning.

The philosophy in designing this environment for research and experiments is that it should have the same general characteristics as a command and control (C^2) planning environment, our main focus of application. However, we did not want to use an actual C^2 planning task partly because of the difficulties in creating scenarios and in obtaining appropriate subjects. Wargames, such as those used in operations research, do not provide the right vehicle for this kind of study, because they focus mainly on the execution of a plan to validate doctrine relating to use of real equipment during combat encounters, not the activity of human planning. Military games sold as toys, although having a strong human participation, also emphasise plan execution and were also judged too complex to permit control over the factors that we believe influence planning. There are almost no examples of suitable experimental tasks and paradigms in the literature that might be used as guidance in constructing an experimental environment for studying C^2 planning (McCann, 1990). This, plus the fact that our work in this area will be exploratory at the beginning, suggests that the overall approach to the specification of an experimental environment should be "start simple and grow". However, the environment should be structured from the outset for increasingly complex task situations.

The environment should permit us to address research issues such as the structure of human planning processes and the information used in planning; the effects of uncertain information on planning; the circumstances under which replanning occurs and how it is carried out; and the effects of computer-based aids on the quality and efficiency of planning.

The paper begins by describing a simple model of a typical dynamic planning situation, using command and control as an exemplar. The model permits the identification of the important characteristics of the C^2 environment that should be incorporated in a laboratory planning task. In the next section, a more extensive description is provided of the typical research questions that we wish to address. An experimental environment for studying planning, called SPLITS is then described, first in a simplified version, and then in increasingly more complex versions. The final section addresses the use of the experimental environment in controlled studies of human planning.

2 THE PLANNING SITUATION

2.1 Description of model

Planning for action in a domain (some *real world*) involves the modelling of the future state of the domain, and the organization of actions that will accomplish the goal of the planner and alter the expected state of the domain in some intended way. The planner can usually monitor the domain through some sensed representation of it (via a *monitoring environment*); plan responses (via a *planning environment*); and order the execution of the planned responses that will alter the real domain.

The planning of events in simple, familiar domains, for example, the events in a typical workday, is usually done completely mentally. In this case, the planner has a well-established internal mental representation of the world that is compared with the desired goal state to determine what actions to take and when. Furthermore he executes the plan himself. Some subcomponents of the planning environment may be external to the planner, such as an agenda used to list and order events, but most of the planning activity happens internally.

In more complex situations, for example, those of business, planning may draw on a highly detailed explicit representation of the world (e.g., data on current company performance, expected product demand, strategies of competing companies, available resources). The planner or planning group -- for often there are several individuals involved in the process -- will likely produce several drafts of the business plan before it is finalized and sent to subgroups in the organisation for execution. Sometimes it is months or even years before the effects of the actions executed on the basis of a given business plan can be detected.

Planning in the command and control situation is similar to that in a business setting, except the loop of planning, execution and feedback is shorter, especially at lower levels in the command hierarchy. Furthermore, there is an active adversary whose goals and actions must be taken account of. The information available to the planner or planning team is only approximate, because of noise and delays in the sensors that detect the state of the battlefield and also because of deliberate deception by the enemy. The planning activity itself is strongly influenced by procedures that have been learned (doctrine), as well as by the external support (e.g., maps) that is provided for assistance.

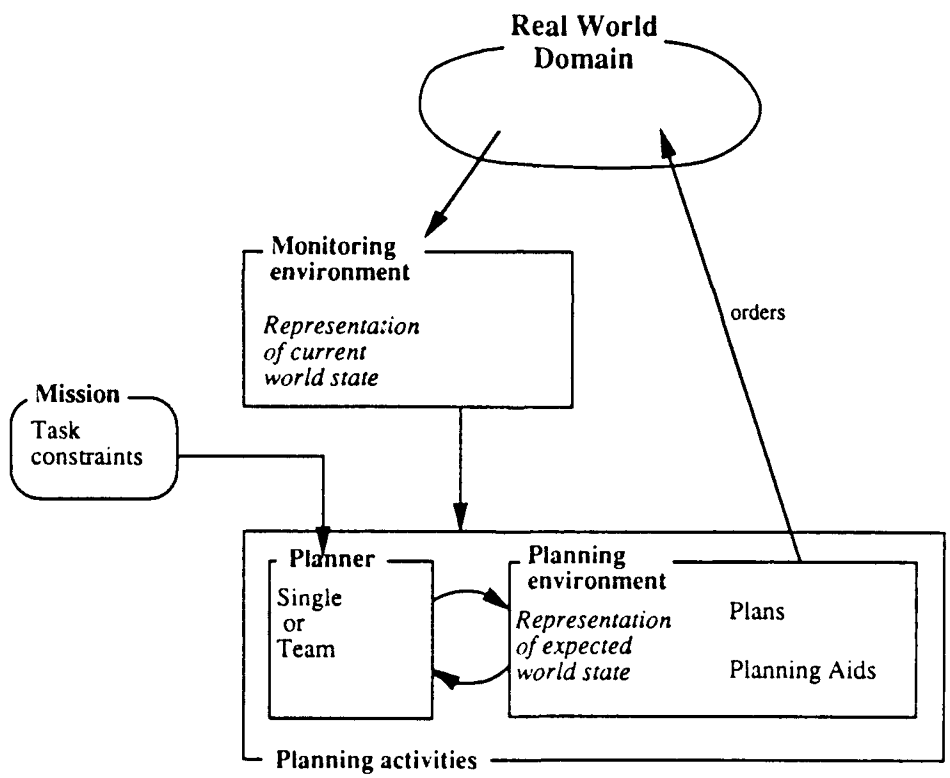

Fig. 1 Components of a planning situation.

We can generalize from these examples to develop a simple model of a planning situation. The main components, as shown in Fig. 1, are thus:

a) the real world domain of objects and events;
b) the monitoring environment, a representation of the real world that is based on sensed information;

c) the mission;
d) the planner or planning team;
e) a planning environment.

2.2 Characteristics of C^2 planning

The model of the planning situation given above can be used as an organizational schema to help further identify the characteristics of dynamic C^2 planning that should be accommodated in the planning task developed for experimental studies. This section expands on those characteristics.

2.2.1 *The domain*

The military planner plans actions in a world that can be divided into objects that are under his control (his Own military resources or Units, such as personnel, vehicles, weapons); and those that are not (those either neutral in the interaction or belonging to the Enemy). In the case of Own and Enemy units, the major characteristics distinguishing combat units within a level in the command organization are *mobility* (which also depends on the terrain), *fighting capacity*, and *sensing* capabilities. Units of different types within the military structure balance these capabilities differently (e.g., tanks have high fighting capacity, relatively low mobility).

Units in the world *interact* with one another in a variety of ways. The primary example of interaction is combat (exchange of fire) between friendly and enemy units. Units are therefore *vulnerable*, in the sense that their capabilities can be reduced or destroyed. Units on the same side also interact: for example, an artillery unit can support the advance of infantry unit. The number of combat and other units of different sizes and capabilities permits the total potential interaction on the battlefield to be very *complex*. The activities and interactions of the different types of units must be *co-ordinated* by the planner for full effectiveness in an operation.

The co-ordination of military operations must be planned in two dimensions: over *time* and over *space*. Own and Enemy units can execute actions in a parallel, *simultaneous* manner in time. The battlefield situation is highly *dynamic*. In addition, the limits imposed by the *Terrain* (type and spatial configuration) play a major role in planning and executing an operation. The terrain limits the degree to which enemy position and strength can be sensed and also limits the mobility of both sides. Furthermore, the characteristics of the terrain itself may be incompletely known.

Finally, the Enemy in the C^2 planning situation is an *active adversary* with goals, and resources. Information concerning these goals and resources is *uncertain*. The planner must make assumptions about the goals of the enemy.

2.2.2 *Monitoring environment*

The current representation of the real world is the starting point for planning: it provides a basis for extrapolation to a future state in which planned actions will be carried out. A representation of the overall battlefield situation is maintained by the operations section as a battlefield map with graphical and alphanumeric annotations. Representations of certain aspects of the battlefield needed for specialized activities (e.g., artillery, air support) are held by other sections in the command post. The information represented on these displays is a filtered amalgamation of data on Own and Enemy state and location and Terrain, provided mainly by lower units. The time taken to pass this information up the chain and the dynamic nature of the domain means that the representation is always *out of date*. Due to the limited sensing abilities of the units, and deliberate deception on the part of the Enemy, the information in the representation is *uncertain*.

2.2.3 *The planning activity*

The activity of planning is driven by a *mission* and takes place in a *planning environment*. The overall goal in military operations is to "win" on a mission by capturing or destroying enemy resources and/or by controlling or occupying territory. The mission is the description of what the planner is to achieve in terms of *tasks* to be accomplished (goals to be achieved) and *constraints* on the execution of those tasks (for example, constraints on the use of resources, on the time by which the mission must be accomplished, etc.). The mission is given to the commander by his superior unit. The degree of definition of the mission depends to some extent on the commander. In principle, it defines *what* needs to be done, but not *how* to do it.

The activity of the planner involves assessment of the mission in the context of the expected state of the world (at the point when the operation is started); the gathering of information on the current state of the world (on Own and Enemy forces, and Terrain, obtained from the monitoring environment); the development of courses of action to alter the anticipated state of the world according to the mission; the selection of one course (the *plan*); and the creation of orders to be sent to subordinate units concerning their missions in the context of the plan. The plan is created at a *sufficient degree of detail*: sufficient that the subordinate units understand clearly what they must do, but not so detailed that the planner is, in effect, making their plans too. Generally, the rule of thumb in C^2 planning is to "think two levels down in the organization" This means that the commander should consider the constraints associated with actions in plans for the next two levels down in the command hierarchy.

The activity of C^2 planning is heavily *time-constrained*. This feature stems in part from a need to react promptly to dynamically changing situations of high uncertainty. It is also related to the requirement that a plan developed at a certain level must be further developed by levels further down in the organization.

Both the activity of planning itself (i.e., the procedures) and the resulting plans are heavily influenced by military *doctrine*. Doctrine is a kind of corporate wisdom, based on expert analysis of both past and anticipated military capabilities and battles. Doctrine dictates a procedure for planning: what steps are carried out, in which order, when and by whom. It also guides the assessment of enemy situation, and the choice of strategy and tactics that might be used to carry out "typical" missions.

Doctrine suggests "good" strategies and tactics to be used in military situations, but it cannot give the "best" plan. In fact, the best plan for a particular military situation is impossible to specify for several reasons. One is the sheer complexity of the battlefield, its objects and their interactions and the number of goals that the many participants are trying to satisfy simultaneously. Not only is the battlefield complex, but there is a large degree of uncertainty concerning the actual events that will occur there. The uncertainty is associated with incidental or low-probability events and it is also generated deliberately by the actions of the enemy. Therefore the number of possible plans that could be considered by the planner to deal with the domain complexity and uncertainty is enormous. Although it is possible to judge a plan against standard criteria, even expert judges will differ in their evaluations of a given plan for a particular situation. Thus, there is *no best plan*.

The goal implied by the mission is accomplished through planning, followed by execution of the plan. Although the emphasis in this description is on planning, it is impossible to divorce planning from execution, since it is through execution that the planner becomes familiar with the characteristics of the domain to be planned in. Thus part of the task of planning involves *monitoring of the execution* of the plan and possibly *replanning*.

Finally, due to the complexity and uncertainty in the environment and the state of the enemy, full and detailed planning of a military operation is not usual. Detailed planning is done for activities near in the future. Detailed planning of events further in the future depends on the outcome of the execution of these earlier activities. Thus, planning in the C^2 environment is characterised by being *concurrent with execution* to an extent.

2.2.4 *The planners*

The characteristics of the planner(s) are also an important influence on the way that planning is carried out. Military planners are *trained* in planning doctrine and procedures through courses, for example, at staff schools and colleges. This training addresses both procedures for planning out a mission at a given military level (e.g. situation assessment, course of action selection, etc.), and the procedures for co-ordinating planning among levels in the organization. A further measure of expertise in planning is developed through *experience* in field exercises.

As mentioned above, the planning of any but the simplest military operation involves the participation of several people, some within the same level of the organizational hierarchy and others at lower and higher levels. At any level, the planning staff consists of at minimum the commander and his deputy (usually the operations officer). At intermediate levels (e.g., Battalion) individuals specializing in aspects of the battle (e.g., intelligence, artillery, logistics) support the planning activity and may even participate in it. At the highest levels, planning is carried out by a separate staff within the C^2 centre. The task is thus *distributed* over *hierarchical organizations within and between levels.*

2.2.5 *The planning environment*

The planning environment provides, to some degree, a way of organizing the information on the state of the world to support the development of the plan(s) to accomplish the mission; and a way of recording the evolving and final plan or plans.

Information on the current state of the domain, represented in the monitoring environment, is incorporated by the planner into the planning environment in either a direct or transformed form. The planning environment also supports the creation of plans and may provide specific additional *aids* to assist the planner. These may take the form of rudimentary drawing and calculation tools or they may be more sophisticated computer-based aids that model the domain and effects of proposed military actions.

2.2.6 *Summary*

In summary, then, the following attributes characterise the C^2 planning situation:

a) The domain against which planning is carried out consists of a large set of Own and Enemy resources, with differing mobilities, fighting capacity and sensing capabilities. The interaction of these objects is complex and dynamic and occurs simultaneously over time and space. The nature of the terrain plays an important role. The enemy is an active adversary with his own goals, which are not fully known to the planner.
b) The planner constructs a plan for the execution of a mission (consisting of tasks and constraints) given by a superior unit. The plan must be at a "sufficient" degree of detail. Although a plan can be evaluated against standard criteria, there is no "best" plan. The planning process is time-constrained, and both it and the plan are influenced by the military doctrine.

c) Military planners are trained in planning and they also gain experience in planning in the field. Planning often involves several participants within a military level of command, and the overall C^2 planning process is influenced by the hierarchical structure of the military organization. Communication within and between levels is important.

d) Planning is carried out against a partial representation of the real world domain, in which some information is uncertain, and much is out-of-date. The representation is principally graphical in nature. The planning environment may provide some tools for representing, evaluating, and disseminating proposed plans.

3 RESEARCH QUESTIONS

We have now considered the characteristics of the C^2 planning task and situation that will need to be modelled in an experimental environment for studying C^2 planning. Before turning to a detailed description of a suitable environment, let us consider the kinds of research questions that the experimental environment must allow us to address.

3.1 Structure of the planning process

We are interested in discovering the basic cognitive processes and procedures used by humans in planning the activity of multiple co-operating resources that must be co-ordinated in both time and geographic space. With the exception of the work by Hayes-Roth and Hayes-Roth (1979), empirical studies of human planning for these kinds of problems have not been carried out.

Two main approaches or models have been proposed for the structuring of the planning process. One, arising out of work in artificial intelligence, not psychology, proposes that planning is carried out in a top-down hierarchical fashion where plans are developed first in a rough form and then in successively finer detail. The other model, the "opportunistic" model developed from the Hayes-Roths' studies, proposes that the movement through levels of plan detail is not strictly top-down, but multidirectional. Decisions about plan steps are influenced by immediately-obtainable goals that seem to be brought into focus by plan simulation. We would like to determine which of these models holds for C^2-type planning problems.

A factor that may influence the nature of planning is the familiarity that the subject has with the task and the planning environment (gained either through practice or training). It is possible that planners experienced with a particular planning problem will know how to prioritise, select and organize the information needed and so their behaviour will be more goal-directed and their planning more hierarchical. We expect, too, that there will be large differences in the way that individuals solve C²-type planning problems. In addition, the nature of the planning environment itself will influence how people represent and structure the planning problem and develop the solution.

The environment for experiments must, therefore, provide a way of eliciting planning behaviour and capturing the cognitive activity of subjects who are planning a task. It must allow for repeated planning trials using similar problems.

3.2 Influence of uncertainty on planning

A second issue that is central to understanding human planning in C² is the effect of uncertain information on planning. Almost all the information used by the military planner is uncertain to some degree: the terrain, the state of enemy resources, and, especially, the intended actions of the enemy. Although research has been done on the effects of uncertainty on decision making, none has considered the effect on plan creation.

In principle, full information about the domain should allow full plan creation before execution is started; in this case, execution would be straightforward. Complete lack of information (full uncertainty) about the domain and resources prohibits planning entirely. In this case, information might be procured by the planner (at some cost) or the execution simply started, thereby permitting the planner to discover characteristics of the domain through interaction with it, and develop a plan along the way. There is a range of possibilities between these two extremes. Probably a degree of uncertainty will have the effect of limiting the extent of planning. An efficient approach for the planner in this case is to create contingency plans which depend on the eventual values of the currently uncertain parameters. Once the uncertainty is resolved, the appropriate plan can then be adopted. Empirical studies will be required to determine whether, in fact, planners behave in this way and whether the procedures for planning are changed by uncertainty.

To permit studies of how uncertainty influences planning, the experimental environment must provide mechanisms for controlling the degree of knowledge the subject has about the spatial and other characteristics of the domain during both the planning and execution phases. It should be possible to control when and in what form new information resolving uncertain information is given.

3.3 Replanning

Although the focus in our work is on how people plan for events in the future, given a certain amount of information about the current state of the domain, it is also of interest to consider what happens when a plan proves to be inadequate or unsuccessful during its execution. If the results of execution of a plan deviate too far from those expected, this may trigger a reconsideration of the current plan and possibly a new stage of planning called replanning. A plan may need to be altered for several reasons: information that was unavailable during the original planning may become available during execution; the domain situation may change dynamically, possibly because of actions of the adversary, thus prohibiting certain planned actions or suggesting different ones; or, the planner may have made an error in creating the original plan.

We are interested first in determining the conditions under which replanning occurs. We suspect that there may be a bias on the part of humans to carry on executing a plan until evidence for its unsuitability becomes overwhelming. Is there a gradual recognition of the need for replanning, or can it be triggered by a particular event that may or may not be anticipated by the planner? If there is an error in the original plan, how is it typically detected once execution starts, and does the planner immediately replan?

A second aspect of the issue concerns the procedures people adopt for replanning. Are there circumstances in which people plan entirely "from scratch" or are they more likely to try to adapt the current plan? How thoroughly are the implications of the adaptations considered by the planner? Are errors in reworked plans more frequent than in original plans?

To permit the addressing of questions on replanning such as these, the experimental environment must permit the replanning process to be captured and provide means by which events or information that might trigger replanning can be made available during execution.

3.4 Computer-based support of planning

The environment provided to the planner for representing the planning problem and for developing the solution can have a great influence on the quality of the plan and how quickly it is created. Our investigations of the planning process will suggest aids that could be incorporated into the planning environment to relieve the cognitive limitations of the planner. Such aids might, for example,

a) Help the planner represent the problem in time and space
b) Store interim states of an evolving plan to permit the planner to retrace the planning steps, for example, during replanning;
c) Evaluate and compare potential complete or partial solutions against criteria set by the planner;
d) Create a fully annotated final plan to guide execution.

The experimental environment should facilitate the development and testing of such aids.

Investigation of the above issues requires an experimental environment that completely and adequately models the characteristics of the application (C^2) in respect of the planning task, the planning environment, the domain and the representation of the domain while, at the same time, permitting control of the characteristics that are believed to influence planning.

4 SPLITS: SIMULATION FOR PLANNING IN TIME AND SPACE

The planning situation that we propose for experimental use is an environment called SPLITS, for Simulation for PLanning in Time and Space. It is intended to satisfy the following criteria:

a) The components of the C^2 planning situation should be modelled and controllable so that their influence on the planning activity can be determined;
b) The planning task given to the subject should not require training in military doctrine and strategies;
c) The planning situation should be configurable in simpler versions, specifically without the adversary;
d) The environment should be incrementally extensible;
e) The environment should allow us to address the kinds of experimental questions outlined above.

The SPLITS environment is described below. First a general description is given of the concept. Then a simple one-player version is described. Subsequent sections explain how the basic version can be extended in complexity. Finally a two-player version is presented.

4.1 **General**

The problem situation against which planning is carried out is a one or two-sided game involving the acquisition of commodities. In the one-player version, the player is successful if he acquires commodities according to some conditions (e.g., in a certain order, in a minimum time). In the adversarial version, one side "wins" by acquiring commodities in a certain time for the least cost in terms of resources.

The experimental environment is centred on a computer-based shopping game played between two players (or, potentially, teams of players). Players must plan the movement of shopping robots through a large warehouse. The overall mission is to pick up certain commodities that are given to them on a shopping list. The spatial layout of the warehouse is a two-dimensional matrix consisting of aisles and shelves of commodities. Players must both plan their own robots' paths through the warehouse (on a planning board) and give orders to the robots for the plan to be executed. The movement of the robots is portrayed graphically and interactively on a monitoring board representing the real warehouse. The first player to get out the door with all the commodities needed wins the game.

4.2 A simple version

A very elementary version of the planning game would involve only one player, who plans a route to be taken by a shopping Unit (characterised as a robot) through the warehouse to pick up the commodities on the list (in any order). This version is analogous to the errand planning task described in Hayes-Roth and Hayes-Roth (1979), although their domain and the subject's task suggested some implicit constraints on the order of errand execution (e.g., pick up the groceries last). In this single-player basic version of the shopping game, the main factor influencing the solution is the spatial layout of the commodities on the warehouse board. This layout could be varied across trials by having the computer place the (fixed) commodities differently on the (fixed) shelves, and, further, by changing the spatial layout of the shelves. Subject performance could be manipulated by limiting the time available for the task. The path selected by the subject could be evaluated (e.g., in terms of length) against a computer-generated solution. The task can be made more difficult by increasing the number of items on the shopping list, or by increasing the size of the warehouse.

In this elementary version of the shopping game, only a very limited set of the C^2 characteristics are modelled, namely Own Unit (there is only one in this case, corresponding to the shopping robot of the planner) and simple Terrain. The task of acquiring the commodities on the shopping list constitutes the mission (from higher authority) of the planner. The movement of the robot through the warehouse and the pickup of commodities are the means by which the task is executed. The combination of list and commodities can be easily varied to allow for replication of mission across trials. The Terrain (the warehouse) can be varied somewhat by changing the spatial layout of commodities.

Let us now consider how the task and the characteristics of the domain can be made more complex, to approach the C^2 situation.

4.3 Varying the task through commodities

The task can first be made more complicated by varying the characteristics of the commodities in ways that might affect task execution. For example, the commodities might have different relative values to the shopper, say, based on "need": bread might be more important than ice cream. The task of the (single) planner might then be "Pick up those commodities on the list with the greatest value within a certain period of time". The values of the commodities would suggest how the order of pickup should be prioritised. In this case, the time to actually move through the warehouse (from square to square in the physical environment of the game board) would have a cost that is factored into the execution of the task (similar to the C^2 environment).

As an alternative, the task could be constrained by requiring that certain commodities be picked up before others (e.g., pick up the heavy items first and the fragile items last, to avoid having the potatoes sitting on top of the cake in the basket).

4.4 Varying the capabilities of the shopping unit

There are two directions in which the Shopping Unit concept can be enriched to approach the C^2 environment. One way is by varying the characteristics of the Units themselves across rounds in the game; the other is by allowing for several Units to be under the control of the planner at one time.

Consider first the dimensions along which Unit capability could be varied. In the C^2 environment, Units differ in

a) their fundamental task capacity (in C^2 terms, they differ in "fighting capability");
b) in their mobility in the operational environment; and
c) in their ability to sense that environment.

The first characteristic, capacity, relates to the principal task, which, in the proposed experimental environment, is the acquisition of commodities. This "capacity for commodities" characteristic could be varied by, for example, limiting the number of commodities that could be carried by one shopping Unit (like a limited shopping cart capacity). Or, if different commodities were assigned different weights, capacity could be modelled as an upper limit on the total weight of commodities that a Unit could carry. This latter would require some fairly complex computations by the planner in trading off, for instance, weight against commodity value.

The effect of the other two characteristics, mobility and sensing, are closely coupled with the characteristics of the Terrain, and may require a bit of imagination to be applied in the context of a shopping warehouse. Mobility can be varied simply and independently of Terrain by varying the speed of travel of the Units. Further, it is possible to imagine that different shopping Units have different degrees or types of mobility: some being able to travel into the deep freeze; others able to climb ladders to get items on high shelves; etc. It is not clear whether this kind of mobility should be continuous in some fashion, or just a one-to-one mapping from shopping Units onto different warehouse Terrain types.

To this point in the description we have assumed that the planner could "see" the whole of the warehouse, and that there was no uncertainty about which commodities were where. This is not the case in the C^2 environment. The Terrain and especially the Enemy information are, to some extent, unknown or uncertain to the planner. Consider now the implications of making some part of the warehouse unknown to the planner. It might be necessary to "buy" information about the layout of the unknown section (in an elementary version from a central information source), which could, for instance, cost the planner time. A more sophisticated way of getting information might be to send directly into the warehouse a special Unit with the means of sensing the information needed. And, further, different Units might have the ability to sense different kinds of commodities.

A more complicated variation of sensing brings the environment even closer to the real-life military one. Here we assume that, instead of having full knowledge about the commodities on the warehouse shelves, the planner only has partial knowledge about the contents of the shelves in general. This situation can be described as "this particular commodity is known to be here, but we don't know what is beside it on the shelf" (although perhaps the unknown commodity could be reasonably expected to be within a certain subset of the total set of commodities, because commodities are grouped spatially in a known way). Under these conditions, the planner might send out special Units to find out exactly what is on the shelves (like a reconnaissance mission for intelligence) early in the planning cycle. Or, if all Units had the ability to sense the commodities that they could carry, then another strategy would be to send a shopping Unit into a likely area in the hopes of finding the commodity needed.

The relationship between sensing capability and the Terrain would have to be worked out in more detail. Presumably a Unit can sense only a limited area of the warehouse around the current position.

There is one more characteristic of a Unit that has not been satisfactorily modelled so far, namely, its vulnerability. In the military environment, Units are vulnerable to deliberate action by the enemy: for example the fighting effectiveness (weapons, ammunition) of a Unit is reduced because of combat encounters with the enemy. Units are also vulnerable due to the cost of moving and working in the combat environment: food, fuel etc. The shopping environment does not suggest an obvious method for modelling the first kind of vulnerability. One way would be to simply limit the time a Unit could spend shopping; Units staying longer than the set time would be removed from play (together with the contents of their shopping basket). The second kind of vulnerability can be adequately modelled by including a cost for moving in the environment, equivalent to fuel cost.

4.5 Playing several units

The preceding discussion suggests the possibility of having more than one shopping Unit available as a resource to the planner, in the same way as in a C^2 environment. Simplistically, this might be desirable if a certain amount of shopping had to be done in a certain time, a time shorter than that required for the pickup of all commodities on the list. In this case, parallel shopping by several shopping Units would be necessary. Another relatively simple case would occur if the list was more than one Unit could carry (e.g. in terms of total commodity weight). Two or more Units might be required. More complex cases can be easily imagined, especially if the Terrain is varied or the layout of commodities uncertain. For instance, a special Unit (i.e. one with particular sensing or mobility capabilities) might be required to find and pickup a certain special commodities while another did the bulk of the "ordinary" shopping. The introduction of several Units provides a more realistic environment for planning co-ordinated movement across time and space. For example, the planner might be required to ensure that Units all come to the exit at the same time. It also allows the possibility of planning co-operative action between Units which individually may not have the capability to carry out the shopping task. This becomes more analogous to the C^2 situation.

4.6 Planning team

One further level of complexity is the extension of this environment from a single planner, controlling a number of units, to a Planning Team among whom the planning responsibilities are divided. Planning responsibility can be divided between team members in a variety of ways. For example, different team members could be responsible, a priori, for the plans for different types of units in the context of an overall mission; or, planning could be divided on the basis of the spatial layout of the store. Alternatively, the mission goal could be subdivided dynamically by the planning team itself into a set of subgoals that team members would be responsible for accomplishing. The way in which the overall planning problem is decomposed and allocated will have a strong effect on the planning process. If a subdivision results in independent subproblems, they can be solved independently by the team members. If, as is more likely, there are dependencies between the subproblems, planners will need to co-operate to co-ordinate their solutions and achieve the best overall solution. The communication between team members will be an important factor in this co-operation, particularly if they are physically separate from one another.

A different extension would be in the direction of modelling the hierarchical nature of the C^2 planning organization by having "lower level" agents (equivalent to sub-unit commanders) actually implement the plan developed by the principal planner.

4.7 Modelling the adversary

The final major component to be considered in the proposed experimental environment is the Enemy, modelled in the shopping environment by the other player. The inclusion of a goal-oriented adversary greatly complicates the planning task since the subject, the planner, must now take account of the potential actions of an intelligent opposition in developing and executing the plan. Not only must the planner decide how to accomplish his own mission, but he must do it faster (or better) than the opposing side. He must thus plan to satisfy two separate goals: one, the accomplishment of the mission, given the existence of the enemy; and the other, the thwarting of the enemy's mission. In experiments with an adversary, the execution phase will play a more critical role since the course of events during execution of the plan cannot be so closely controlled: they will be a function of the reaction of the enemy. Thus replanning during this stage is more likely to happen. For the game to be balanced, the capabilities and limitations of the two sides should be equivalent.

As a first step in the direction of incorporating an active adversary, the game should probably only involve one friendly shopping Unit and one Enemy, with exactly the same capabilities. Possibly, they should have precisely the same shopping list (task) as well. The degree of interaction between the two sides in this case would depend partly on the availability within the warehouse of the commodities on the lists. If the demand exceeded the supply (and thus players were competing to acquire limited commodities), a high degree of interaction between the sides would be expected. How might this interaction be executed? One way would be to give the players the capability to "block" the movement of the opposition, for example, by laying down some (temporary) obstacles to movement through the aisles.

A second level of complexity would be introduced if the two sides had different shopping lists, either known or unknown to the other side. If there was overlap between the lists (i.e., common items), a strategy for the planner would be to plan to get the common items first, before the other side did. More realism could be introduced by giving the planner a means of finding out which items were on the other side's list. Presumably there would be a cost associated with this "intelligence". An additional degree of uncertainty concerning the Enemy can be incorporated by varying Enemy characteristics such as shopping basket capacity, or mobility. The Enemy task can also be varied in a controlled way by manipulating the shopping list (e.g., by assigning priorities to the commodities to be picked up); or by manipulating the start and end point of the route travelled through the warehouse. Even with only a single Enemy Unit, variation in these dimensions gives the potential for a fairly complex problem for the planner.

The complexity could be much further increased by permitting the Enemy to play several shopping Units of different capabilities and limitations, analogous to the case of Own Units. If the location and resources of these Enemy units is uncertain and dynamic, the planning problem then becomes quite similar to that in a C^2 environment.

4.8 **Summary**

The various configurations described above offer a spectrum of experimental environments that can be used to study planning processes in situations similar to C^2. The domains and associated planning tasks range from the simple to the complex. The dimensions along which complexity can be varied are:

a) the task, in terms of type of commodities to be acquired, their value, and interactions between commodities;
b) the capabilities of shopping Units, in terms of capacity, mobility, sensing, and vulnerability;
c) the number of different kinds of shopping Units played;
d) the Terrain, in terms of layout, and uncertainty;
e) the Enemy, in terms of uncertainty in task, capabilities, and actions;
f) the size and organizational structure of the planning team.

These factors can be varied independently to study their effect on the planning activity.

5 USING SPLITS IN EXPERIMENTS

This section considers some aspects of using the game as an experimental environment. We expect that the mechanics of the experimental setup and execution will be different depending on whether the Enemy component is modelled or not.

The execution of the game will be monitored through a computer-displayed two-dimensional matrix that represents the Terrain of the warehouse. The planner will have available information about Own shopping Units (location and characteristics), Terrain, Enemy, the mission, i.e., the shopping list and any constraints.

In the simple case where there is no Enemy, and the information concerning Terrain and Own Units is certain, then the task of the subject will be to plan the shortest route that allows pickup of all commodities on the list. Planning itself will be carried out in a planning environment separate from the monitoring (game) environment. Initially, the planning environment could simply consist of a paper map of the warehouse that assists the planner in developing and selecting the route. The subject will be required to give a continuous verbal report of planning. The creation of a satisfactory route (the plan) then permits the subject to give orders concerning movement and pickup of items to the robots. Execution of the orders will result in an update of information on the game board (the monitoring environment).

This setup forces a necessary separation of planning from the execution of the plan. It suggests a two-phase experimental trial: first planning and then execution. However, a subject's plan may fail in execution, in which case he will need to go back (possibly more than once) into the planning environment for replanning of the current plan, using the current world situation as a start point.

A rough estimate the length of a trial for these conditions (e.g., with a 10-commodity list, in a 10 x 30 warehouse) is 10 minutes. Replications of this condition can be made by varying the commodities layout and the shopping list. In theory, a "best" route can be calculated by the computer and compared with the one selected; the score would be the difference in length. Videotaping of the planning phase will capture verbal and graphical protocols from the subject as the planning task is being executed and will allow for analysis of the information and reasoning involved in route selection. It would also be desirable to have a means for replaying the execution of an experimental trial.

The complexity of the task can be varied by increasing the length of the list, putting constraints on the order of the pickup, or providing more than one instance of a required commodity (in the warehouse). Similarly the characteristics of the shopping Unit and the Terrain can be made more complex as described in the previous section. As the amount of information needed for planning increases, it cannot all be presented to the subject at the same time. Therefore an interface to the computer information system must be designed to give subjects access to the relevant data in the monitoring environment.

The insertion of uncertainty about the location of commodities (i.e., Terrain uncertainty) need not change the basic format of experimental task execution. In this case, the monitoring environment shows the planner only a subset of the total information about the Terrain. The accuracy of the information in the subset can be experimentally manipulated to study the effects on planning. If the subject is permitted to reduce the uncertainty (for example, by buying information), the cost of doing so could be incorporated into the score for the route selected. If the subject must carry out planning without a full resolution of the uncertainty, then the real world state can be shown to the subject at the end of the trial (and used as a basis for scoring). More trials would be needed in this condition.

A planning board, a part of the planning environment, would be the mechanism for (experimentally) keeping track of the current plan. The protocols and notations for using a computer-based planning board would need to be developed. During the game the planner must follow the prescription of the current plan; if changes or extensions to the plan are needed, the planner must deliberately make these known on the planning board.

It is difficult to specify absolute measures of plan quality (i.e., execution-independent) that could be used as objective measures of planning performance. However, one measure of the goodness of the plan is the number of times that it needs to be changed during execution. "Good" plans incorporate a better model of the situation and expected events and accommodate the various contingencies; therefore we intuitively expect that they will not need to be changed so often. This kind of measure might be considered here, although it is hard to specify at this stage what might constitute a "change" in a plan.

Independently of the domain and the monitoring environment, the planning environment itself could be manipulated to study the effect of different kinds of situation representations and planning aids. For example, a computer-based planning environment could be developed that allows access to the monitoring environment; that acts as a workspace for the development of plans; and that holds a record of the current plan. In conditions of Terrain uncertainty, the planning environment can also hold the planner's running hypothesis concerning the suspected location of commodities.

The incorporation of an intelligent Enemy into this environment (even into a relatively simple version) greatly complicates the experimental situation, since the planner must now account for the potential actions of the Enemy (i.e., model its behaviour). The expected interplay between the two sides is a large factor in the initial plan, and the inability to fully predict all situations and reactions by the Enemy limits, de facto, the extent of initial planning that is actually carried out. Further planning (and replanning) is done in conjunction with execution of the established plan. There are two implications for the experimental methodology. First, the planning phases on both sides are highly interleaved with the execution phases and furthermore, the actions on the two sides are interleaved with each other. Second, it is no longer possible to compute a "best" plan, since there are too many variables (especially those related to the goal-oriented actions of the Enemy); therefore it is difficult to get a measure of the "goodness" of the planner's plan.

Finally, let us consider the mechanics of the game when two players are planning and executing. One possibility is to base the play on "turns" in the manner of most board games (like chess). One side would alternate with the other, taking "actions" in the environment. Depending on the extent of the Terrain, the degree of certainty in the Terrain/Enemy, and the characteristics of the Units, these actions would range from simply moving a single Unit in the warehouse, to setting down obstacles, sensing, etc. The other possibility would be to permit play by both sides simultaneously, a situation closer to the actual C^2 environment, and one that is much more dynamic. In this case, there is a need for some kind of external clock that regulates the speed of movement of Units in the warehouse (depending on mobility). With multiple Units, this version could be quite complex.

6 CONCLUSIONS

The planning game offers a flexible and extensible environment for studying human planning processes. It models the kind of planning situation found in C^2, providing the same components and characteristics and allowing manipulation of the factors that we believe influence the planning activity:

a) a real world domain consisting of Units, the shopping robots, with different capabilities and possibilities for interaction; a Terrain, the warehouse, in which Units move and act simultaneously in time and space; and an Enemy with similar resources;
b) a planner, the subject, whose training on the task can be controlled;
c) a well-defined, but complex task of planning robot routes and commodity pickups under constraints;
d) a separate planning environment in which the plan is created, and which can be augmented by different aids;
e) a means of executing the plan and a mechanism for replanning if necessary;
f) a monitoring environment giving filtered results of execution of the plan.

The environment allows us to address research questions such as the structures and procedures used by human planners; the effects of uncertain information on planning; the circumstances under which replanning occurs; and the effects of computer-based aids on the quality and efficiency of planning.

REFERENCES

Hayes-Roth, B. & Hayes-Roth, F. (1979). A cognitive model of planning. Cognitive Science 3, 275-310.

McCann, C.A. (1990). Human cognitive processes in command and control planning. 1: Identification of research issues. Report IZF 1990 B-18, TNO Institute for Perception, Soesterberg.

Soesterberg, August 1, 1991

Carol McCann

C.A. McCann

REPORT DOCUMENTATION PAGE

1. DEFENCE REPORT NUMBER (MOD-NL) TD 91-2170	2. RECIPIENT'S ACCESSION NUMBER	3. PERFORMING ORGANIZATION REPORT NUMBER IZF 1991 B-10
4. PROJECT/TASK/WORK UNIT NO. 733.2	5. CONTRACT NUMBER B91-35	6. REPORT DATE August 1, 1991
7. NUMBER OF PAGES 27	8. NUMBER OF REFERENCES 2	9. TYPE OF REPORT AND DATES COVERED Final

10. TITLE AND SUBTITLE

Human cognitive processes in Command and Control planning. 2: SPLITS - An environment for experiments

11. AUTHOR(S)

C.A. McCann and P.J.M.D. Essens

12. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

TNO Institute for Perception
Kampweg 5
3769 DE SOESTERBERG

13. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

TNO Defence Research
Schoemakerstraat 97
2628 VK Delft

14. SUPPLEMENTARY NOTES

15. ABSTRACT (MAXIMUM 200 WORDS, 1044 BYTE)

The report describes a laboratory-based task and environment for empirical investigation of human planning of activities in time and space. The environment, called SPLITS, presents planners with problems analogous to those encountered in command and control environments. The problem situation against which planning is carried out is a computer-based shopping game that can be played by one or two players. Aspects of the shopping environment, such as the layout of the store and its commodities and the number, mobility and sensing capabilities of the shopping robots, can be varied to give a range of planning task complexities. The report describes how SPLITS can be used to address research issues such as the structure of human planning processes and the information used in planning; the effects of uncertain information on planning; the circumstances under which replanning occurs and how it is carried out; and the effects of computer-based aids on the quality and efficiency of planning.

16. DESCRIPTORS Command and Control Man-Machine Interactions Methodology	IDENTIFIERS Military Planning Experimental Paradigm

17a. SECURITY CLASSIFICATION (OF REPORT)	17b. SECURITY CLASSIFICATION (OF PAGE)	17c. SECURITY CLASSIFICATION (OF ABSTRACT)
18. DISTRIBUTION/AVAILABILITY STATEMENT Unlimited availability		17d. SECURITY CLASSIFICATION (OF TITLES)

VERZENDLIJST

1. Hoofddirecteur van TNO-Defensieonderzoek

2. Directie Wetenschappelijk Onderzoek en Ontwikkeling Defensie

3. { Hoofd Wetenschappelijk Onderzoek KL
   Plv. Hoofd Wetenschappelijk Onderzoek KL

4, 5. Hoofd Wetenschappelijk Onderzoek KLu

6. { Hoofd Wetenschappelijk Onderzoek KM
   Plv. Hoofd Wetenschappelijk Onderzoek KM

7, 8, 9. Hoofd van het Wetensch. en Techn. Doc.- en Inform. Centrum voor de Krijgsmacht

10. Dr. D.G. Pearce, Defence and Civil Institute of Environmental Medicine, North York, Ontario, Canada

11. Dr. J.J. Fallesen, ARI Field Unit Leavenworth, Ft. Leavenworth, Kansas, USA

Extra exemplaren van dit rapport kunnen worden aangevraagd door tussenkomst van de HWOs of de DWOO.
